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System Engineering Report

Cavity Wall Temperature Study

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(NASA-TM-110679) CAVITY WALL TEMPERATURE STUDY (NASA. Ames Research Center) 5 p

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From: Dan Machak
Subject: Cavity Wall Temperature Study

Attached is a copy of a report that studies the temperature of the forward cavity bulkhead.

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Introduction

This report gives the results of a study that examined the relationship between the amount of insulation on the bulkhead walls, the amount of heat leaking into the cavity from the cabin, and the subsequent increase in temperature of the surface of the bulkhead walls over that of the ambient cavity air. This study will assist in setting the specification of the allowable heat leak into the cavity and the maximum surface temperature increase.

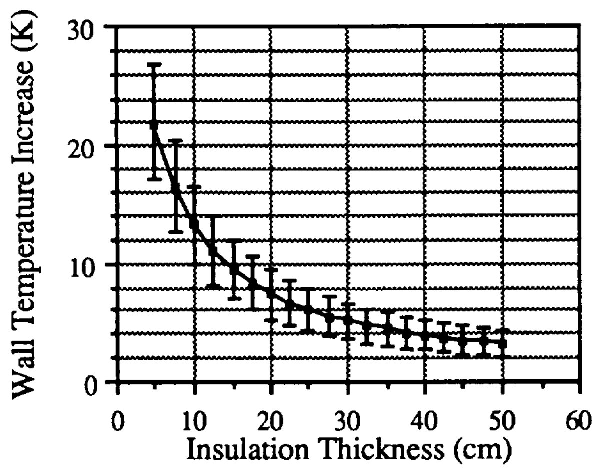
Limitations Of This Study

1. Only heat transfer due to conduction was considered. The effect of mass leaks and heat loss due to radiation of the walls to the cold sky were not considered.
2. The case shown below is for the forward bulkhead. The temperature increase for the aft bulkhead would be the same for a given amount of insulation, but the amount of heat flow would be different since air bearing takes up more of the bulkhead area on the aft bulkhead.
3. The heat flux values are across the bulkhead only; the study didn't examine the total heat flow into the cavity.
4. The temperature of the caging device was not considered.
5. The insulation thickness was assumed uniform over the bulkhead except for the area of the caging device.

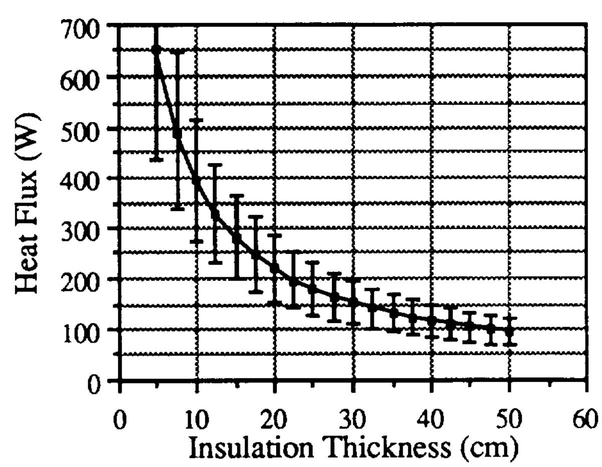
Results

The following plots show the increase in the cavity wall temperature and the heat flux into the cavity as a function of the insulation thickness. The uncertainties in the values are denoted by the error bars. See Appendix B for a discussion of the uncertainties.

Effect of Insulation on Cavity Wall Surface Temperature



Effect of Insulation on Heat Flux into Cavity



From the surface temperature plot, we can see that for even 50 cm of insulation, the rise in wall temperature is in the range of 2° to 4° K which would not meet the current specification of a maximum 2° K temperature difference of cavity surfaces over cavity air. The current design of the cavity has 10 cm of insulation which corresponds to a 10° - 17° K temperature rise. Since space is limited in the cavity, it is unlikely that enough insulation will be able to be used to reach the current goal. Therefore either another method of thermal isolation, such as the false wall concept, must be used or the design goal must be relaxed.

Analysis

The analysis was performed using basic thermal laws. A brief description of the model is given here.

The total heat flux from the cabin to the cavity is calculated by:

$$Q = k_t A(T_{cab} - T_{cav}) \tag{1}$$

Where A is the area of the bulkhead, T_{cab} and T_{cav} are the cabin and cavity temperatures, respectively, and k_t is the total conductance and is a function of k_i, and k_{bl}, the conductances across the insulation and the boundary layer respectively. It is found as follows:

$$k_t = \left(\frac{1}{k_i} + \frac{1}{k_{bl}}\right)^{-1} \tag{2}$$

k_i is given by:

$$k_i = \frac{\kappa_i}{d_i} \tag{3}$$

where κ_i and d_i are the conductivity and thickness of the insulation. k_{bl} is calculated from a standard equation for forced convection on a flat plate.

$$k_{bl} = \frac{Nu\ \kappa_a}{L} \tag{4}$$

L is a reference length, κ_a is the conductivity of air, and Nu is the Nusselt number, given by:

$$Nu = .33 Re^{1/2} Pr^{1/3} \tag{5}$$

where Re and Pr are the Reynolds number and Prandtl number of the flow inside the cavity.

After getting the total heat flux, finding the temperature drop across the boundary layer on the inside of the cavity wall gives the temperature difference of the bulkhead above the cavity air. This is found using the following equation:

$$\Delta T_w = \frac{Q}{A k_{bl}} \tag{6}$$

Where ΔT_w is the increase in the wall temperature over that of the cavity air.

Appendix A: Parameters

Following is a list of the parameters used in the study along with their uncertainties.

Cavity temperature:	$230° \pm 5°$ K	Stagnation temperature
Cabin temperature:	$295° \pm 2°$ K	Room temperature
Bulkhead area:	$21.7 \pm .5$ m^2	SOFIA Phase A report
Bulkhead reference length:	$2.0 \pm .25$ m	SOFIA Phase A report
Velocity of air at bulkhead:	5.0 ± 2 m/s	Zeiss phase B final report
Insulation conductivity:	$.05 \pm .005$ W/(m-K)	Zeiss phase B final report
Air conductivity:	$.0215 \pm .0004$ W/(m-K)	Standard Atmospheric tables FL410
Air density:	$.290 \pm .02$ kg/m^3	Standard Atmospheric tables FL410
Air viscosity:	$(1.55 \pm .025) \times 10^{-5}$ kg/(m-s)	Standard Atmospheric tables FL410
Air specific heat:	$1005.0 \pm .1$ J/(kg-K)	Standard Atmospheric tables FL410

Appendix B: Error Analysis

There are a number of uncertainties in the data used to perform this analysis, especially the value used for the velocity inside the telescope cavity, which was obtained using a crude wind tunnel model. There can also a variation in the temperature of the cabin and the cavity. The analysis was done for nominal values of all the quantities. The uncertainties in each quantity was taken into account in a first order error analysis and plotted using error bars on the graph. For the case when the insulation thickness was varied, the errors in the heat flux and the wall temperature increase are:

$$\mathbf{d\Delta T_w} = \left(\frac{\Delta T_w}{k_{bl}} + \frac{\Delta T_w k_t}{k_{bl}^2}\right)\mathbf{dk_{bl}} + \frac{\Delta T_w k_t}{k_i^2}\mathbf{dk_i} + \frac{\Delta T_w}{(T_{cab} - T_{cav})}(\mathbf{dT_{cab}} - \mathbf{dT_{cav}})$$

$$\mathbf{dQ} = Q\left(\frac{\mathbf{dk_t}}{k_t} + \frac{\mathbf{dA}}{A} + \frac{(\mathbf{dT_{cab}} - \mathbf{dT_{cav}})}{(T_{cab} - T_{cav})}\right)$$

where the boldface indicates the uncertainty in that quantity. The errors of the heat transfer coefficients are given by:

$$\mathbf{dk_t} = \left(\frac{k_t}{k_i}\right)^2\mathbf{dk_i} + \left(\frac{k_t}{k_{bl}}\right)^2\mathbf{dk_{bl}}$$

$$\mathbf{dk_{bl}} = \frac{k_{bl}}{2V}\mathbf{dV} - \frac{k_{bl}}{2L}\mathbf{dL}$$

$$\mathbf{dk_i} = k_i\frac{\mathbf{d\kappa_i}}{\kappa_i}$$

Note that the uncertainties in some of the quantities such as the cavity and cabin temperatures, the insulation conductivity and the air velocity in the cavity are arbitrarily chosen so as to give a conservative estimate of the wall temperature and heat flux. Uncertainties in the values of the air properties are meant to reflect a range of operating conditions.